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EFFECTS OF CONTINENTAL GLACIATION ON AGRICULTURE*

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Some reference is made in recent geographical texts to the effects of the Pleistocene continental ice sheets on the industry, commerce and agriculture of those areas of North America and Europe which they invaded.[1] Such passages are in the main confined to broad generalizations. No detailed, comparative summation of the favorable and adverse effects of the former presence of the ice on the human occupation of the glaciated regions is attempted. Limitations of space in view of the breadth and involved nature of the subject are no doubt responsible for the failure of the authors to consider it more fully. Yet the wide areal distribution of phenomena due to glaciation, and the very complexity of relationships these have to modern civilization, invests them with great geographical interest.

In this paper it is attempted to present and analyze only one phase of this broad subject, namely a comparative study of the beneficial and harmful effects of the ice invasions on agriculture.

Agriculture is crop production. The comparative success of agriculture is measured by the amount, character and permanence of crop production. An enumeration and evaluation of the factors due to glaciation which make for and against the *optimum* of each of these units, or their sum, will, therefore, express the relative benefit or harm done to agriculture by the invasion of a given region by glacial ice.

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* This paper was awarded the Walker Prize in Natural History, 1913, by the Boston Society of Natural History, Boston, Mass.

[1] Bowman, I.: Forest Physiography, N. Y., 1911, p. 486 and elsewhere.
Salisbury, R. D.: Physiography, N. Y., 1907, pp. 228-289, 316.
Salisbury, Barrows & Tower: Elements of Geography, N. Y., 1912, pp. 405-407, etc.
Dryer, C. R.: High School Geography, N. Y., 1912, pp. 122, 353.

TOPICS TREATED

Even with the limitation imposed on this paper a wide array of topics needs to be considered. If some of these topics seem to be inadequately treated this may be attributed in part to their number. In the list of topics and sub-topics, given below, relative importance has in some instances been subordinated to convenience and continuity of discussion.

1. GENERAL RELATIONS:
    - (*a*) Geographical Position of the Glaciated Areas with reference to Modern Civilization.
    - (*b*) Comparison of the Agricultural Status of Glaciated Areas with that of Non-Glaciated Areas.
    - (*c*) Climatic and Topographic Position of Glacial Zones of Erosion and Deposition.
2. EFFECTS DUE TO RELIEF CHANGES CAUSED BY GLACIATION:
    - (*a*) Increased Diversity of Relief and its Agricultural Consequences.
    - (*b*) Modification of Relief and its Agricultural Consequences.
    - (*c*) Effects of Relief Changes on Ground Water Conditions as Affecting Agriculture.
3. GLACIAL SOILS:
    - (*a*) Characteristics Distinguishing Glacial Soils from other Soils, and their Agricultural Significance.
    - (*b*) Variation in Age of Glacial Soils with respect to Crop Productivity.
    - (*c*) Textural Variations of Glacial Soils in relation to Diversified Agriculture.
4. EFFECTS ON AGRICULTURE DUE TO HYDROGRAPHIC PHENOMENA RESULTANT FROM GLACIATION:
    - (*a*) Glacial Lakes and their Effects on Local Climates and Agriculture.
    - (*b*) Agricultural Relations of Deposits in Drained and Filled Glacial Lake Basins.
5. SUMMARY.
6. CONCLUSION.

1. GENERAL RELATIONS

(a) Geographical Position of the Glaciated Areas with reference to Modern Civilization. Pleistocene continental glaciation was a phenomenon centering essentially about the North Atlantic Basin. Around the North Atlantic Basin are centered, also, the leading nations of the modern world. In the generalized statements of the textbooks, it is sometimes suggested that the leadership of

such nations is largely accruing from natural advantages they have derived from continental glaciation. Without question many of the natural resources of these nations are owing to the invasion of the ice. Whether, however, what has been gained, on the whole, more than balances possible losses due to the ice advances cannot be so readily judged by cursory examination. Geographical factors other than glaciation, moreover, may be determinant in this general grouping of modern, virile peoples around the North Atlantic, and historical considerations may not be wholly set aside. Moreover, it must not be forgotten that France, Italy, New Zealand and Australia, to name examples without the glaciated regions, are also in the van of modern progress.

To put the general effect of glaciation on the comparative advancement of nations to a critical test would be most difficult, as may readily be conceived. Pertinent objections and exceptions could be made against any argument or figures cited to demonstrate either the positive or negative side of so broad a proposition: *i. e.,* that the advanced status of nations within the glaciated areas was or was not due to the effects of the ice invasions. Limitation of the question, however, to the general effect of glaciation on the agricultural status of a country or region makes available certain statistics which, if not conclusive for the broader areas, are nevertheless interesting and, applied to narrower areas, are quite significant.

(b) Comparison of the Agricultural Status of Glaciated Areas with that of Non-Glaciated Areas. The percentage of cultivated land of the total area of France, practically unglaciated, may be compared with a similar percentage of cultivated lands in Germany, an adjacent country of which a large part of the total area was glaciated. In 1900 Germany with a total acreage of 133,550,020 acres, had 86,596,830 acres of land under cultivation and in pasture, or nearly 65 per cent. of the whole. France with a total area of 130,799,000 acres had 59,329,593 of these in cultivation and pasture, or nearly 45 per cent. of the total number.[2] The two countries have nearly equal areas, but France has the more genial climate. Despite this climatic advantage of France the figures indicate that Germany has 20 per cent. more of productive land. Also Germany supports nearly a third more population than does France, a fact which is in keeping with the amount of difference in productive land. The excess value of Germany's imports of agricultural products (principally food stuffs) over exports, expressed by a number

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[2] *The Statesman's Year Book*, 1911, London. Articles on France and Germany.

is 676; while for France it is 929.[3] Here again Germany clearly has the advantage though she supports a greater population.

While these statistics demonstrate rather conclusively the agricultural superiority of Germany it does not follow that the evident difference in crop productivity of the two countries is due to glaciation. Such a deduction depends on the fundamental assumption that all other factors influencing crop production in the two countries are the same, and this assumption can be only an approximation. For example, the relative fertility of different French soils is in a very large measure dependent on the character of the underlying geological formation from which each has been derived. Whether Germany would have had an equal, greater, or less amount of fertile soil than France, of residual and alluvial derivation, is impossible of determination. Again the proportionate area of highland and lowland in the two countries would need to be considered. Nor does it suffice to offset the agricultural benefit France derives from her more genial climate by the fact that some of the fertile areas of Germany do not owe their fertility to glaciation.

Very recent statistics for the United States make possible a somewhat more accurate comparison, than the foregoing, of the agricultural status of glaciated areas with non-glaciated areas, inasmuch as the figures are more detailed, and as such differences as appear may be ascribed to glaciation with considerable assurance. In the following table appear agricultural statistics for states in the humid agricultural region of the country. On the left are grouped states whose territory lies wholly within the glaciated area; on the right those without the zone of glacial influence.

GLACIATED STATES OF THE EASTERN HUMID REGION OF THE UNITED STATES[4]

NAMES	TOTAL AREA IN 1000'S OF ACRES	AREA IN FARMS IN 1000'S OF ACRES	TOTAL VALUE OF FARM LANDS IN 1000'S OF DOLLARS
Minnesota	51,749	27,675	1,019,102
Wisconsin	35,364	21,060	911,938
Michigan	36,787	18,940	615,258
New York	30,498	22,030	707,747
Vermont	5,839	4,663	58,385
New Hampshire	5,779	3,249	44,519
Maine	19,133	6,297	86,481
Massachusetts	5,145	2,876	105,532
Rhode Island	683	443	15,010
Connecticut	3,085	2,185	72,206
Illinois	35,867	32,522	3,090,411
Iowa	35,575	33,930	2,801,974
	265,504	175,870	9,528,563

Percentage of total area in farms 66 per cent.
Average value per acre of farm land $54.00

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[3] Chisholm, G. G.: Handbook of Commercial Geography, Eighth Edition, London, 1911, pp.566–568.

[4] *Agriculture Bulletins*, 13th Census of the U. S., 1910, Bureau of Census, Dept. of Commerce and Labor.

NON-GLACIATED STATES OF THE EASTERN HUMID REGION OF THE UNITED STATES

NAMES	TOTAL AREA IN 1000'S OF ACRES	AREA IN FARMS IN 1000'S OF ACRES	TOTAL VALUE OF FARM LANDS IN 1000'S OF DOLLARS
Delaware	1,258	1,039	34,938
Maryland	6,362	5,057	163,452
Virginia	25,768	19,496	394,659
North Carolina	31,194	22,439	343,165
South Carolina	19,517	13,512	268,775
Georgia	37,584	26,953	370,353
Florida	35,111	5,253	93,738
Alabama	32,818	20,732	216,944
Tennessee	26,680	20,042	371,416
Kentucky	25,716	22,189	484,465
West Virginia	15,374	10,026	207,076
Oklahoma	44,425	28,859	649,066
Arkansas	33,616	17,416	246,021
Mississippi	29,672	18,558	254,022
Louisiana	29,061	10,439	187,803
	394,156	242,010	4,285,893

Percentage of total area in farms 61.4 per cent.
Average value per acre of farm land $18.00 nearly.

While this tabulation shows a nearly equal percentage of total area in farm lands (therefore further justifying the comparison of the regions) it also exhibits a remarkable disparity in average farm land values between the glaciated and non-glaciated areas, the value of the former being three times as great. As glaciation is the most important physiographic factor of difference between the two regions, the difference in values may well be ascribed to its effects. Yet the comparison, like the preceding one, is between extensive regions remote enough from each other to permit of a wide variety of factors being operative in bringing about differences in their agricultural status. Thus their climatic, topographic and geologic structure conditions can not well be correlated. A comparison of smaller glaciated and unglaciated areas, immediately adjacent to each other, will serve, therefore, as a check on the integrity of the deduction that the differences so far found are due to glaciation.

Some 9,000 square miles of territory in southwestern Wisconsin constitute the larger part of the Driftless Area, a region unique in that it was entirely encompassed by the ice advances, but itself shows no traces of ever having been covered by them. The elevation, geological structure and climate of this Driftless Area are in no important respect dissimilar from those of the immediately adjacent glaciated areas. Writing about the contrasts between the glaciated and driftless portions of Wisconsin, Whitbeck[5] says: "In the driftless area only 43 per cent. of the land is improved, while in the drift covered area 61 per cent. is improved, a difference of 18 per cent.'' Further: ''The value of farms and farm buildings averages nearly 50 per cent. greater per square mile in the drift-covered counties than in the driftless.'' He summarizes other comparisons he has made, bearing on the relative agricultural status of the contrasted areas as ''all clearly in favor of the glaciated region.''

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[5] Whitbeck, R. H.: The Glaciated and Driftless Portions of Wisconsin. *Bull. of the Geogr. Soc. of Phila.*, Vol. IX, No. 3, July, 1911, pp. 19–20.

Like results are obtained on comparing statistics of adjacent counties in Indiana within and without the glaciated area. Thus the average value of farm lands in Daviess Co., within the glacial area, is \$50-\$75 per acre; while in Martin Co., next east, outside the glaciated area, the average value is \$10-\$25 per acre. Similarly Greene Co., glaciated, shows average values of \$25-\$50 per acre, while Lawrence Co., adjacent, unglaciated, shows \$10-\$25 per acre. Daviess Co. has 90-95 per cent. of its total area in farms, Martin 80-90 per cent.; Greene Co. 90-95 per cent., Lawrence 80-90 per cent.[6] That these relations hold generally, as well as for selected typical counties, is shown especially clearly by a map of Indiana (Fig. 1) on which have been set down the average farm values, per acre, by counties and the extent of the several ice invasions outlined.

While it is quite apparent from these comparisons that, as regards agriculture, the status of the glaciated lands is superior to that of the unglaciated areas, it must not be assumed, as is commonly done, that this is wholly due to differences in soil fertility, nor that only benefits were conferred by glaciation. Moreover, the comparisons so far made have been between non-glaciated regions and regions of glacial deposition, *i. e.*, places where the accumulation of drift was in excess of the erosive effects of the ice. It is, therefore, necessary, before finally adjudging the benefits to agriculture of glaciation to outweigh any damage done by the ice occupation, to consider also, whether, in regions where glacial erosion predominated, the possible injuries done by it may not more than counterbalance the benefits conferred on the areas of drift accumulation.

(c) Climatic and Topographic Position of Glacial Zones of Erosion and Deposition. While a few glacialists still question the ability of glacial ice to erode notably deep rock basins, or to reduce considerably the height of summit areas, all students of the subject

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[6] Data from: *Agriculture Bulletin*, Indiana, 13th Census of the U. S., 1910, map, p. 2; Leverett, F.: The Illinois Glacial Lobe, *U. S. Geol. Surv. Monogr. XXXVIII*, 1899, Plate VI.

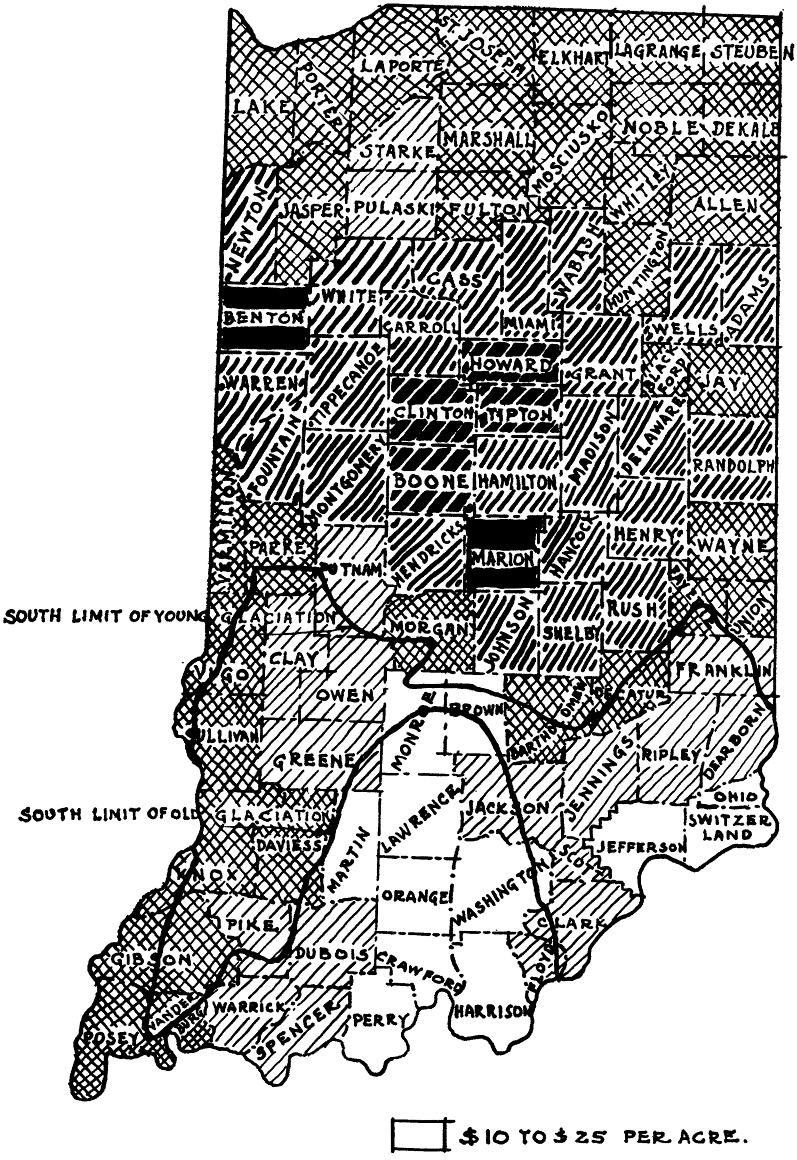

FIG. 1—Map of Indiana Showing Relative Value of Farm Lands by Counties in Old and Young Glaciated and Non-Glaciated Area, after 1910 Census of the U. S. and Leverett.

are unanimous in conceding the effectiveness of the continental ice sheets in scouring off the cover of residual material and rotted rock which had, in all probability, accumulated in preglacial times over the areas central to the ice dispersion. The result of such ice-scour, in its extreme condition as it occurs in Norway and the northern part of the Scottish Highlands, is typically described by Geikie[7] in a single sentence as follows: "Seen from a height, the ground appears like a billowy sea of cold grey stone." Similar conditions in North America occur in the Laurentian Plateau of Canada of which Bell says[8]: "The Archean country is thoroughly denuded of everything down to the bed rock." Since agriculture is primarily dependent on the existence of a soil cover, and since sufficient time has not elapsed to permit of the renewal, by weathering, of a residual mantle in the postglacial period, there can be no doubt that the agricultural availability of the regions of glacial erosion was seriously impaired by the ice-scour. Moreover, the regions of glacial erosion approach those of drift accumulation in areal extent. If, therefore, only the relative areas of the contrasted regions be considered, the damage done by the removal of the soil cover in the one, might well equal the beneficial effects conferred on the regions where deposition predominated.

It is, therefore, fortunate for mankind, that the regions of glacial erosion are all such as would in any event (except that of a much warmer preglacial climate persisting into the present, if continental glaciation had not occurred) have been unavailable for crop production of a high order. Because of climatic or topographic conditions, or both, the regions of glacial erosion are, in general, unsuited for cultivation. Inasmuch as such factors are independent of glaciation the damage done by the ice in removing the soil cover, in so far as the areas themselves are concerned, is not to be counted either as an agricultural gain or loss.

The general centers of ice accumulation and dispersion (practically coincident with the regions of glacial erosion) are for the greater part situated in comparatively high latitudes. Thus in North America, the Labradorean, Keewatin and Cordilleran centers are all situated in the Boreal or Arctic climatic provinces as characterized by Russell.[9] A leading climatic feature of the Boreal province is its low mean annual temperature—in general from 32°-40° F. Because of this, and especially also because of the shortness of the growing season, agriculture is of small importance. In the Arctic province the conditions are even more severe. It is interesting to note, further, that the Labradorean center is a plateau with elevations ranging between 500 and 2,000 feet above the sea, and that on the lowlands of the St. Lawrence Valley immediately beyond its southern edge, where climatic conditions favor a higher development of agriculture, is also found the beginning of the regions of drift accumulation. Similarly the Cordilleran center comprises high, steep, mountain areas, topographically unsuited for agriculture; while in the central plains of the continent, where hot continental summers favor agricultural development at higher latitudes than in the upland regions to the west and east, occur also the depositional zones of the marginal areas of the glacial ice moving out from the mountains and from the Keewatin center.

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[7] Geikie, A.: Text Book of Geology, Fourth Ed., 1903, Vol. 2, p. 1309.

[8] Bell, R.: On Glacial Phenomena in Canada. *Bull. Geol. Soc. Amer.*, Vol. 1, 1890, p. 295.

[9] Russell, I. C.: North America, New York, 1904, pp. 201-202 and Plate III.

In Europe the glacial centers of ice dispersion of northern Scandinavia, Finland and Lapland occupy even higher latitudes, and though on the Norwegian coast normal climatic conditions due to high latitude are somewhat offset by the modifying influence of the Gulf Stream Drift and its accompanying warm, on-shore winds, the climatic conditions are nevertheless as severe as in the Boreal province of North America. Moreover, the Scandinavian Peninsula on the whole forms a plateau with elevations over 4,000 feet, rising highest on the west coast where otherwise the climatic conditions would be most favorable. Finland and Lapland are notably inhospitable climatic regions lying beyond the general northern limit of agricultural land.

The Scottish Highlands, second in importance, in Europe, as a center of ice dispersion and a region of predominant glacial erosion, lie much farther to the south than the Scandinavian area, but their agricultural importance, excepting the glacial factor, is minimized by the fact that they also are upland areas with average elevations of 1,500 feet above sea level. While the mean annual temperatures of this region are only slightly lower than those of agricultural England, the elevations are sufficiently great to promote a very high rainfall, the annual precipitation being eighty inches and over. This amount is excessive for agriculture, especially since it is distributed rather uniformly throughout the year. Such a climate may be characterized as "raw." The same description applies in the main to the lesser centers of ice erosion in the British Isles; the Southern Uplands of Scotland, the English Lake District, North Wales and the Irish mountains. All of these are highland areas and have a rainfall of sixty inches or over.

In Europe, as in North America, the lowlands immediately adjacent to the highland areas of ice erosion are notably seats of glacial deposition. Here again, also, climatic conditions favor agricultural development. Thus favorable conditions of climate and thick deposits of drift are coincident. In the Lowlands of Scotland for example, "Wide areas of the central counties are covered with it [till] continuously to a depth varying from two or three feet up to one hundred feet and more. But as we follow it towards the mountain regions it becomes thinner and more interrupted."[10] Similarly the agricultural district of southern Norway and Sweden is made up of morainic and outwash deposits,[11] as are also, in large part, the central agricultural plains of Ireland. It may be questioned, indeed, whether the preglacial residual materials of the latter two regions would not have lent themselves better to agricultural pursuits than the boggy conditions and refractory morainic accumulations introduced in these areas by glaciation. However, the general agricultural utility of these lands is largely influenced by climate, and they do not constitute large enough areas in any event to affect, appreciably, previously stated conclusions in regard to the generally favorable effects on agriculture by reason of glacial deposition.

Several minor areas of ice dispersion and erosion in North America still remain to be considered. These are the New England Highlands, the Adirondacks and local areas in the western mountains. While these are all upland areas, in general unsuited, topographically, for agriculture, it is worth noting that in them also the general rule holds that glaciation denuded the slopes and summits, leaving them with only a thin veneer of till in place of their former residual cover, but resulted in a thick deposit of drift in the valley bottoms and lower areas. This relation is discussed in more detail in later paragraphs. Here it need only be stated that the average result was to make the unfavorable agricultural sites more unfavorable, but to improve the favorable ones, probably on the whole a net gain in desirable agricultural lands.

Finally it should be noted that almost the total areas of the regions of glacial erosion are, or were originally, forest lands; and to a forest crop they are climatically and topographically best adapted. Certainly, therefore, glaciation must have left a sufficient nucleus of soil over these areas to make possible the forest growth, if indeed it is not possible, as has been stated, that a forest can grow in soil formed of its own humus.

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[10] Geikie, James : The Great Ice Age, London, 1894, p. 15.

[11] Geikie, A.: Text Book of Geology, Fourth Ed., London, 1903, Vol. 2, p. 1332.

Summarizing, then, the general relations of agriculture and glaciation, as considered under the three heads above, it is clearly apparent that the total effect of glaciation has been beneficial to agriculture. On the other hand some of the effects of glaciation were detrimental. That the beneficial effects are not wholly due to soil fertility has also been suggested. In this discussion and analysis a consideration of the effects of the various factors due to glaciation, especially as operative in the regions of drift accumulation, is, therefore, next in order.

2. Effects due to Relief Changes caused by Glaciation

(a) Increased Diversity of Relief and its Agricultural Consequences. Increased diversity of relief due to glaciation may be the result of either ice erosion or depositional accumulations. The effect of ice erosion in accentuating topography is manifested most conspicuously in regions of great diversity of rock structure within narrow areal limits; in places where larger areas and bands of relatively resistant rocks are in immediate juxtaposition with rocks of little resistance to ice erosion; and where the ice sheets invaded regions of rather bold preglacial relief. Morainic ridges and drumlins are the most important forms (from the standpoint of this discussion) of depositional nature which heighten the relief; of minor bearing, because of less frequent occurrence and areal extent, are kames and eskers.

The exposure of a great variety of rocks within small areas is characteristic only of regions of disordered geological structure, namely mountains and districts of worn-down mountains. Within the glaciated areas such regions are found principally in the sections where glacial erosion was predominant, sections which, as has been indicated, are also of little agricultural importance. Thus such great variety of rock structures is found on the Laurentian Highlands of North America, and much of the relief that these have at the present time is due to differential glacial erosion of their diversified bed rock.[12] The same thing is true of the Scottish Highlands where rock basins are extremely plentiful. It is quite certain, also, that some of the inequalities of relief, giving rise particularly to the lake basins, that occur in New England, the Adirondacks, the Lake Superior Highlands and the Lake Region of Finland, are of this origin. In the Adirondacks the broader valleys with cultivated bottoms are primarily due to preglacial weathering and "graben" faulting. Of these Kemp[13] says that the bordering "faults and their escarpments were doubtless much freshened by the Labradorean ice sheet, which plucked away from their faces the loose rock, sheeted by the parallel faults. In this way the relief was heightened during the Glacial Period." As figured by Kemp, these scarps are too steep for even forest growth over a large part of the area of their faces. But, as it has been shown that all these regions are in general agriculturally unfit for other reasons than glaciation, there is no need to consider in detail the effect which heightening of their relief by such differential glacial erosion has had on their comparatively small crop production. It will suffice to state that the general result was to give rise to steeper slopes and to that extent introduce an unfavorable condition affecting even the forest growth.

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[12] Bowman, I.: Forest Physiography, New York, 1911, pp. 565-566.

The contact line of igneous rocks and sedimentary strata, or better, where the latter overlap the former is the most important occurrence where glacial erosion has been effective in increasing the diversity of relief due to the juxtaposition of resistant and relatively non-resistant rock formations. The St. Lawrence, Mohawk and Hudson-Champlain depressions, the Great Lakes valleys and the Connecticut Valley are the most conspicuous examples of this kind in the glaciated portions of North America; the Scottish Lowlands in Europe are not of exactly the same type. Although all these areas, and similar occurrences of lesser note were, without doubt, depressions developed in preglacial times, yet Tarr[14], quoting various authorities, assigns to glacial erosion a part in the carving of each of the Great Lakes, the Hudson-Champlain and the Mohawk valleys. Bowman[15] cites glacial erosion as a factor in the development of the Connecticut Valley. As the St. Lawrence Valley and the Scottish Lowlands were also channels of considerable ice movement, ice-scour was probably influential to some extent in giving them their present topographic expression. However, later glacial deposits largely obscured the effect of this on their bottoms, and, since such depressions were preglacially bordered by escarpment and fault slopes, glacial erosion, in its visible phenomena, probably did no more than steepen these slopes and clear away such talus accumulations as may have given rise to a gentle incline from their base to summit. The net result of such action as effecting agriculture would be to enlarge the area of level land at the base of the cliffs.

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[13] Kemp, J. F.: Physiography of Adirondacks, *Pop. Science Monthly*, Vol. LXVIII, March, 1906, p. 203 and Fig. 8.

[14] Tarr, R. S.: The Physical Geography of New York State, New York, 1902, pp. 183, 189, 206, 239.

[15] Bowman, I.: Forest Physiography, New York, 1911, p. 660.

That this was specifically the case in the Mohawk Valley and that, in addition, glacial erosion may have added considerably to its width of cultivable area is indicated by Brigham[16] who says the valley "continues broad and open toward Little Falls with a concavity of bounding slopes which suggests powerful glacial erosion." As to the probability of effective glacial erosion under such conditions of rock structure Bell[17] says: "When unaltered strata lie at low angles on a nucleus of igneous rock, and the ice moved off the latter against the upturned edge of the stratified rock great erosion has always taken place." The Mohawk valley, in the region referred to by Brigham, constitutes a trench 1,500 feet deep and from twelve to twenty miles wide.

Since the water surfaces of the Great Lakes present unbroken plains, it cannot be strictly held that glacial erosion in carving their basins has increased the diversity of relief. But as so much area has been, by this means, made unavailable for agriculture, the effect of such erosion may well come under this head. Considered from this viewpoint the elimination of the large area of the Great Lakes basins, which were preglacially probably river valley plains, was an important, harmful effect due, in part at least, to glacial erosion. In this connection it is, however, interesting to note that land areas have been reclaimed as well as lost by glacial action. Thus in Europe the Baltic would overflow wide tracts of the plains of Northern Germany if the glacial deposits of that region were removed, for these frequently descend below the level of the sea[18]. Similar encroachment of the sea on the land would occur in England and North America if the present glacial deposits in the valleys were to be removed.

Some of the instances cited above could as well have been referred to as special cases of accentuation of relief, by glacial erosion, of the more general condition where the ice sheets invaded regions of bold preglacial relief. Indeed the effects on agricultural relations under all three of the conditions are very similar. But the most striking development of these effects occurs along the northern and western edge of the Appalachian Plateau in western New York and northwestern Pennsylvania and Ohio. In those regions the ice moved from a comparatively level plains region into a maturely dissected upland, with the result that its main lines of flow were directed by the north-and-south valleys extending parallel to the direction of ice movement; although the ice did overtop the higher elevations in at least the northern part of the district. The heightening of relief by glacial erosion under such conditions of concentration of ice flow, has, perhaps, its most marked expression in the Finger Lakes region of western New York, where it gave rise to what have been termed "through" valleys. Such valleys extend uninterruptedly through from the St. Lawrence to the Susquehanna drainage systems, the former rock divide between them having been cut away by the ice, so that the divides between north-and-south flowing streams are now illy defined and situated on low morainic or other glacial deposits. The walls of such valleys are steep, their sides straight and they show a marked absence of projecting spurs.[19] In some places the steepness is sufficient to make the valley wall a cliff. These valleys have been profoundly modified by glacial erosion, both by deepening and broadening. Not only the main north-and-south valleys, but also the transverse east-and-west valleys show to some extent these effects of ice-scour, and to a less marked degree the tributaries of secondary size reveal the same characteristics. The sides of the valleys are forest-covered, but their broad flat bottoms are all under cultivation. It is clearly apparent that the area of valley agricultural land in this upland region has been increased by the heightening of the relief by glacial erosion.

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[16] Brigham, A. P.: Topography and Glacial Deposits of the Mohawk Valley, *Bull. Geol. Soc. of Amer.*, Vol. 9, 1898, p. 184.

[17] Bell, Rob.: On Glacial Phenomena in Canada, *Bull. Geol. Soc. of Amer.*, Vol. 1, 1890, p. 296.

[18] Geikie, J.: Ice Sculpture, New York, 1908, p. 244.

Glacial erosion, in heightening relief, exerted on general agricultural relations one detrimental effect which, though indirect, deserves mention. It made farm transportation in the eroded plateau district much more difficult. The upland areas are fairly level, and though they are less valuable than the valley lands, they measure a large portion of the area. The trunk transportation lines, the railroads and the markets are in the valleys. The roads from these to the hill farms often need to go straight uphill for from 400 to 800 feet. In some places the grades are so steep as to prevent access to the nearest railroad station. This makes the growing of such bulk crops as potatoes, to which the soils are

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[19] Tarr, R. S., Watkins Glen-Catatonk Folio, No. 169, U. S. Geol. Survey, 1909, Field Ed., pp. 16, 18, 21, 218, 223.

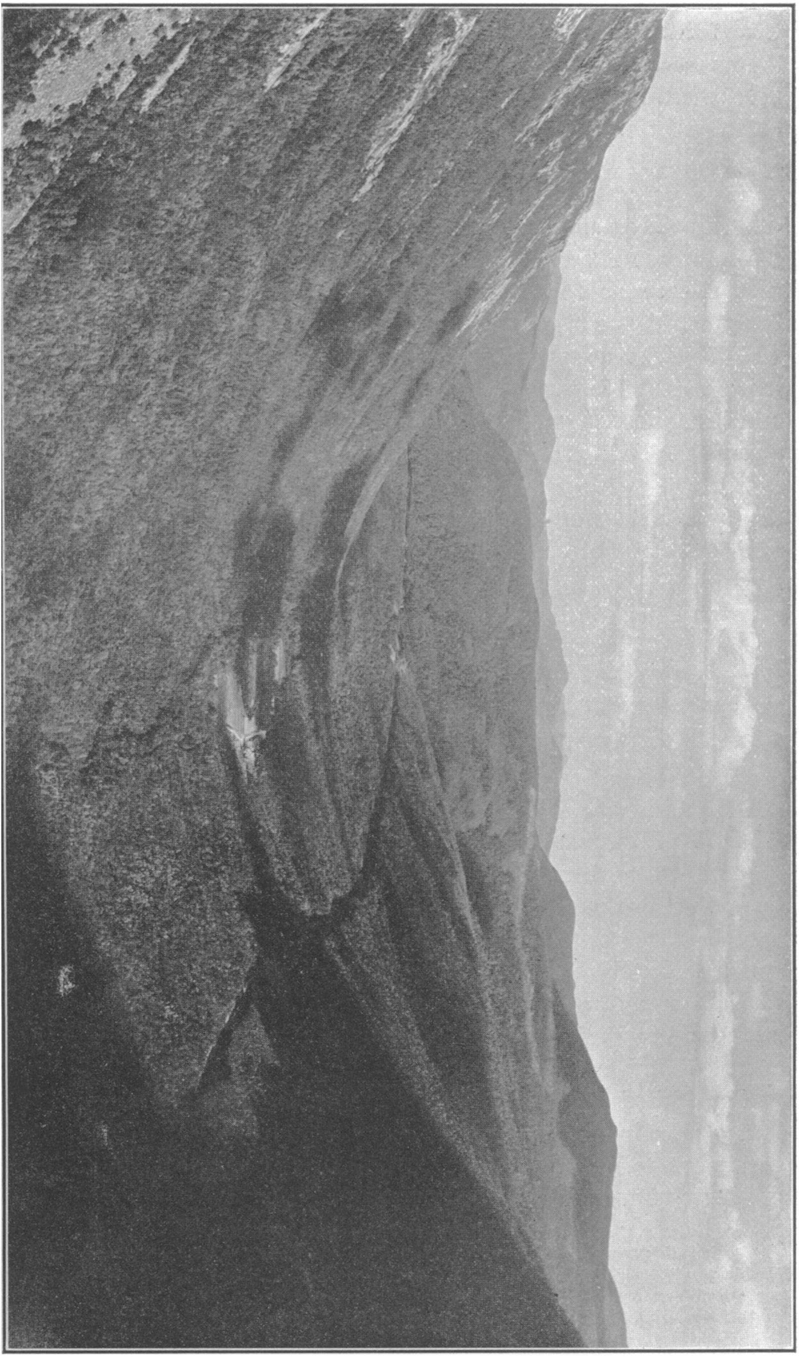

FIG. 2—Crawford Notch, N. H., from Mt. Willard. Slopes steepened by ice erosion. Photo copyright, 1894, by H. G. Peabody.

adapted, often unprofitable.[20] While not in this plateau section, Crawford Notch (Fig. 2) in New Hampshire illustrates beautifully the character of such ice-eroded and steepened slopes. The valley here was also parallel to the general direction of ice movement, northwest to southeast, as shown by the striations, and no doubt[20a] was similarly carved out by the deeper, main ice currents.

It is perhaps inaccurate to ascribe any *increased* diversity of relief in the glaciated regions to depositional accumulations, because the morainic ridges, drumlins and other forms of glacial deposits that rise above the general level of the land rest, as a rule, on basement deposits of the same origin, of wider areal distribution and of more level topographic expression. These basement deposits mask the underlying rock topography which, under the moraines and other elevated forms of drift deposit, may have had a much stronger relief than these give the land at present. As this, however, is only conjectural while the moraines actually exist, some account must be taken of the effect of their elevations and slopes on agricultural operations.

On the map, Fig. 3, are indicated the positions of the morainic belts and drumlin areas of the eastern agricultural part of North America. This map, however, exaggerates the relief distribution of such forms because the width and continuity of the bands as shown is too great, and because comparatively level lands are included within the tracts delineated as morainic and drumlin areas. While some of the morainic masses rise to heights of 150 to 300 feet and are distributed over zones three, five or even fifteen miles in width, making an exceedingly irregular topography, others are little more than broad, smooth, masses, rounded banks of drift.[21] Drumlins also vary from massive hills 100 to 200 feet high, which may be three or four miles long, to indefinite swells in the drift surface. In Europe, moraines are conspicuously developed only in south Norway and Sweden, on the Baltic Ridge of northern Germany and in Finland and West Russia. Drumlins occur in Ireland and Scotland but only sparingly, if at all, in continental Europe.

Considered as topographic irregularities the occurrence of the larger moraines and drumlins must on the whole be counted as a detriment to agriculture in that their slopes are often too steep

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[20] Warren, G. F., and K. C. Livermore: An Agricultural Survey. Agri. Exp. Sta. of the College of Agric., Cornell Univ., *Bull. 295*, pp. 437, 458, 560.

[20a] Since this paper was written J. W. Goldthwait in an article, "Glacial Cirques near Mt. Washington," *Amer. Journ. Sci.*, Vol. XXXV, Jan. 1913, p. 12, cites Crawford Notch specifically as a probable example of a glacially steepened "through valley."

[21] Chamberlin, T. C., in Geikie, J.: The Great Ice Age, 3rd Ed., London, 1894, p. 741.

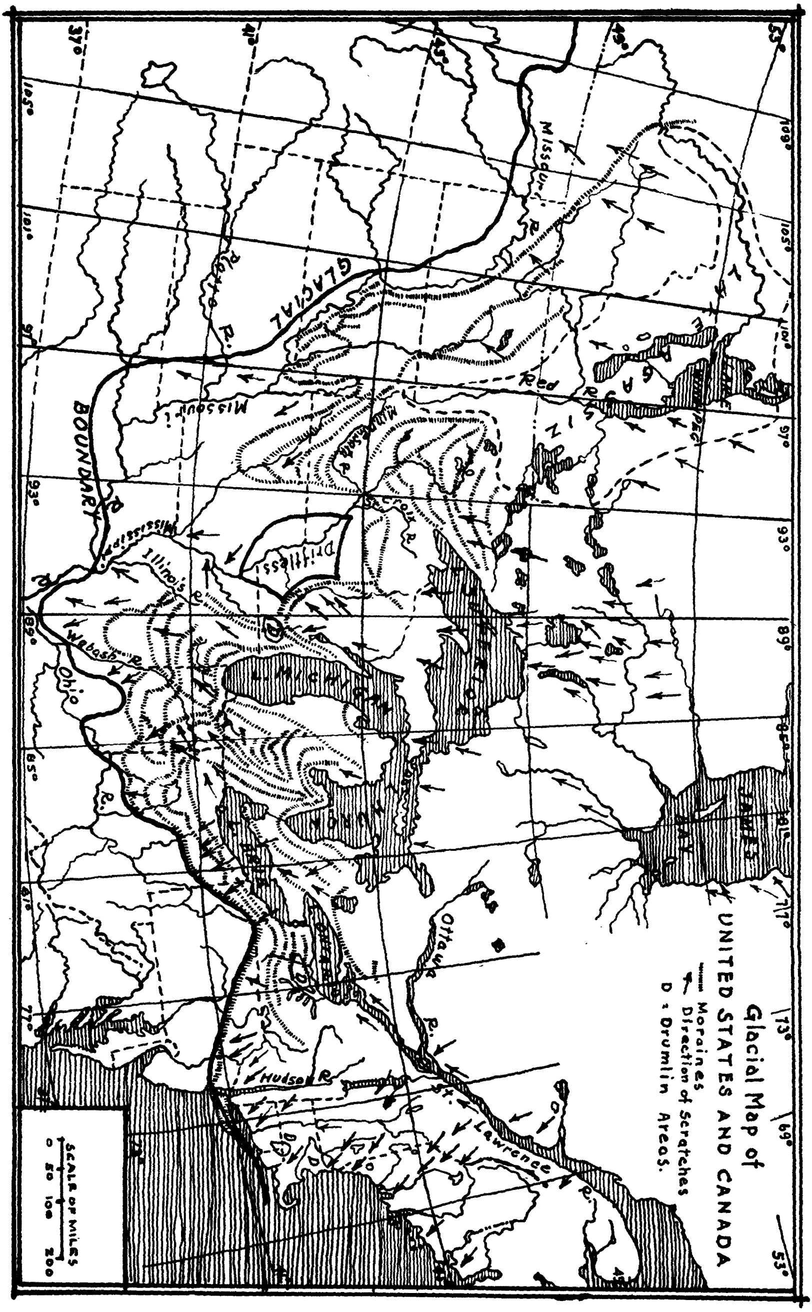

Fig. 3—Map showing Extent of Glaciation and Distribution of Glacial Phenomena in the United States and Canada. After Dryer.

for cultivation, and in that the irregularities of a well-developed morainic or drumlin zone make it difficult country to bring under the plow. But since the relative area occupied by moraines of such strong expression is small, the loss due to this is probably not great. Where the moraine is developed in broader, lower tracts of thickened drift its slightest slopes often promote good drainage conditions without interfering with tillage operations. Soils on drumlin slopes are usually well drained and in New York are well adapted to fruit trees, especially apples and cherries.[22] On the other hand the depressions of a typical kettle moraine area, low-lying pockets with rims uncut by drainage gaps, are consistently shunned by fruit growers and truck gardeners because they have poor air drainage. The cold, heavier air slides down the slopes and collects at the bottom of such pockets, as they have no outlets at the lower levels.

(b) Modification of Relief and its Agricultural Consequences. In the literature descriptive of regional glaciation occur a multitude of references to the effect that the ice invasions resulted in a general reduction of the preglacial relief and that this was accomplished both by glacial erosion and by deposition of drift. In order to understand why this should be the case it is necessary to consider for a moment the nature of the preglacial topography in representative areas and the way in which such topography would be affected by glacial processes.

Processes of weathering, and the erosion of running water, tend to etch the land surface into an intricate relief pattern, bringing into topographical prominence all structural and petrographic differences that may exist in the bed rock of a given region. While the beginning and end stages of a normal cycle of erosion are marked by relief of little expression, it must be remembered that the youthful stage is of very short duration, and that undissected peneplains are practically non-existent in the geological present. Some phase of the middle stage of normal topographic maturity is common on the land surfaces of the globe.

While it cannot be maintained that the preglacial erosion surfaces of the regions invaded by the continental ice sheets had all been developed to a typical stage of maturity in the normal erosion cycle, it is true that the plains areas of both Europe and America that were covered by the glaciation had a much more diversified topography due to dissection than they now possess. Over the broad interior of North America, a peneplain developed in the Tertiary had been uplifted and dissected to various stages of maturity before the ice invasions of the Pleistocene occurred. In eastern and southern New England, an extensive peneplain, developed in the Cretaceous, was uplifted and much dissected in the Tertiary—in fact again reduced to local peneplains over the areas of less resistant rocks. But a later uplift resulted in the further dissection of the more resistant portions of the Cretaceous peneplain and a redissection of the local early Tertiary peneplains. In Europe a very irregular and disordered rock structure underlies the North German Plain; and the preglacial plains of western Russia probably also had a topography of some diversity due to denudation. Similarly the agricultural plains of central and southeast England, north of the Thames, possessed a diversified topography developed by the action of normal denuding agents on rocks of varying age, resistance, and elevation above sea level.

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[22] Whitney, Milton: Use of Soils East of the Great Plains Region, U. S. Dept. of Agric., Bur. of Soils, *Bull. 78*, p. 106.

Nor is it necessary to confine this characterization to plains areas. A multiplicity of minor topographic irregularities, ridges and furrows, is typical as well of the surface of the major relief features of a mountain country, or of the pyramidal masses of a dissected plateau region. As these tend to the old age stage their lines become more flowing; but, as long as they have a significant elevation, variations in structure will make an impress on the topography of their slopes and summits. This would be true of the preglacial Adirondacks, the Catskills, the northern portion of the Appalachian Plateau and the New England members of the Appalachian mountain province. In Europe it would apply to the Southern Uplands of Scotland, the English Lake Region, and the mountains of Wales.

Both the erosional and depositional processes of glacial ice in continental masses are peculiarly adapted to the destruction of just such surface irregularities as it appears must have been characteristic both of the plains areas and the sections with larger relief, now constituting the glaciated regions, preceding the Pleistocene. The action of the ice may best be likened to that of a huge rasp, scouring off the high points and filling the hollows between them with the debris so acquired or, indeed, with that carried from the remoter regions central to the ice dispersion and of predominant erosion. Where the initial relief was great, *i. e.*, in the mountain and plateau regions invaded by the ice, the erosional effect in general was to round off the summit ridges, to replace peaks by dome forms and to make the valley slopes smooth and regular, eliminating or truncating spurs. If, indeed, the valleys were in some instances greatly deepened and their slopes made steeper, they were at the same time widened and their floors made essentially level by drift deposit on the retreat of the ice. This is true of the valley of the Connecticut in New England, of the Mohawk Valley and the larger valleys of the Adirondacks, of the Catskill Mountain valleys; and applies also to the through valleys in the Appalachian Plateau in New York and western Pennsylvania and to the Appalachian valleys and the Triassic lowland area of northern and western New Jersey. The same set of phenomena are characteristic of the Scottish Lowlands, the Lake District of England and the mountain region of Wales. Photographs of the larger valleys of any of these regions almost invariably illustrate these conditions more or less typically. (Fig. 4.)

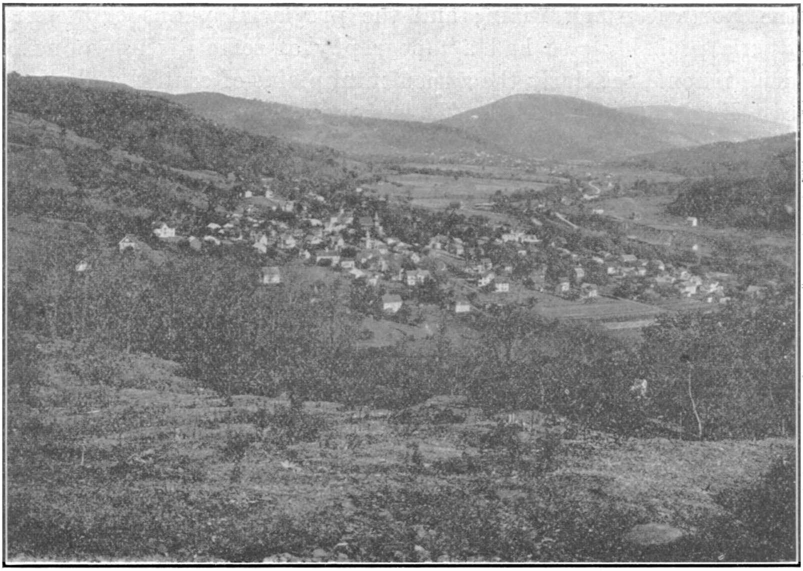

Fig. 4—Valley of the East Branch of the Delaware River at Margaretville, N.Y. Shows filling and leveling of the valley floor with drift deposits. The valley sides are ice-eroded, showing characteristic striation and grooving at many points, locally.

Such modification of the relief by glaciation, in regions having topographic units of marked difference in elevation and large mass; was not, however, wholly favorable to agriculture. The slopes and summits of the uplands, which may preglacially have had a deep cover of residual soil, were most attacked by the ice erosion, as they offered the greatest obstacles to the ice movement. Consequently the residual soil cover and the rotted rock beneath were commonly wholly removed from the exposed areas, and, because of the lobation of the ice on its retreat, glacial deposits in such regions were, by marginal and subglacial streams and moraine accumulation, largely concentrated on the valley bottoms. As a result, glacial deposits are usually found to thin out on the hill slopes and tops, only a thin veneer of rocky till being left behind to cover the glacially eroded, fresh-rock surfaces. The thinness and stoniness of the upland soils due to glaciation must, therefore, be considered as a detrimental effect of glaciation on agriculture. But as this thinning of the soils on the slopes and summits has probably led to a conservation of larger areas to forest than would have been the case if the thicker preglacial soil cover had remained intact and available for cultivation, it may be that the value of the forest and the effect of its cover on the rate of run-off are also very important compensating factors.

The New England region as a whole includes both the mountainous areas to the west and north and the dissected peneplain area to the south and east. Taken together these districts are often cited as typically illustrative of the harmful effects of glaciation on agricultural conditions. It is, therefore, worth while to make special mention of the features of this region in this connection. It has been conjectured that the interstream areas, constituting the uplands of the dissected peneplain, were preglacially blanketed to a considerable depth with residual soil and rotted rock, despite the Tertiary uplift and dissection. All of this weathered material the ice scoured off down to fresh rock, and doubtless it also wore down the elevations and reduced the inequalities of the uplands to some extent, though these are not considered to have been great. In so far, however, it modified the preglacial relief. In the weaker structures of the fresh rock the ice also commonly eroded basins. In the mountainous portions of New England glacial erosion was even more effective and probably sufficed to round off the ridges quite notably, in addition to removing their surface irregularities and covering of weathered material.

On its retreat the ice left only a comparatively thin veneer of soil on the uplands of the peneplain and the slopes and summits of the higher elevations of the mountain country. Moreover, this soil is often very stony, containing from 20 per cent. to 80 per cent. of boulders, some of them quite large. The large size of these erratics is due to the generally massive and durable character of the fresh bed rock of the region in which the ice was quarrying in its final erosive stages. Such fresh bed rock material, because it was acquired last, naturally formed the bulk of the deposits laid down on the melting away of the ice. In patches on the upland, and quite uniformly in the valley bottoms, thick deposits of finer grained outwash and other glacial materials were accumulated.

Thus it appears that New England was unfavorably affected agriculturally by the glaciation because a large proportion of the preglacial level lands of the region consisted of the interstream upland areas where glacial erosion was most effective and deposition feeble, and the glacial soils left behind consequently thin. In what were probably, in many cases, preglacially, rocky gorge valleys, thick deposits of drift were laid down, and their bottoms accordingly built up, leveled and widened. But these areas comprise a relatively small percentage of the whole region. Moreover, the thin soils of the uplands were cluttered by large boulders because the bed rock of the region was structurally massive and durable, furnishing large fragments to the ice erosion, little susceptible to glacial grinding while in transport.

It is, however, precisely because (in direct contrast to the New England region) the great agricultural areas of both North America and Europe were essentially plains regions, possessing topographic diversity of great detail but of a relatively low order of relief, and regions typically underlain by stratified rocks, thin bedded, much jointed and little resistant, rather than massive and durable, and regions wherein the ridge lands were of lesser area than the low lands, that glacial modification of relief both by erosion and deposition has been so beneficial a factor in determining agricultural conditions. The narrow, little-resistant ridges, were readily worn down. The minor irregularities of the surface were literally submerged in glacial deposits twenty, fifty, one hundred and even five hundred feet thick. The material of these deposits was essentially fine grained, available for tillage, because of the character of the bed rock from which it was derived. Over the extensive areas of the plains the ice spread out in a thick continuous sheet and, on its retreat, confluent outwash and till deposits made great reaches of strikingly level land. This leveling process is possibly the most important glacial factor influencing agriculture. To it, primarily, Whitbeck[23] ascribes the greater agricultural prosperity of the glaciated as contrasted with the driftless portions of Wisconsin:

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[23] Whitbeck, R. H.: Contrasts between the Glaciated and Driftless Portions of Wisconsin, *Bull. Geogr. Society of Philadelphia*, Vol. IX, No. 3, July, 1911, p. 19.

"Glacial filling, and to a smaller extent, glacial erosion, have made the drift covered portion of the state smoother than is the driftless region. This has increased the proportion of land that can be tilled." Furthermore, it must not be forgotten that, since the grains constitute the most important staples in the food supply of the world, it is of exceeding consequence to agricultural prosperity that the larger areas of tillable land in any considerable region be suitable for their growth. In this connection the levelness of the glacial plains is a factor of great significance. Altogether it is probable that the reduction in relief brought about by glaciation is the most important of the beneficial effects that have made the ice-invaded regions of greater agricultural value than adjacent lands of similar history, except for this influence.

(c) Effects of Relief Changes on Ground Water Conditions as Affecting Agriculture. In the regions of predominant glacial accumulation, which are, as far as the glaciated regions are concerned, coincident with that portion of such areas as are climatically available for agricultural development, the soil mantle is uncommonly thick. Its average depth in northern New Jersey is calculated at between twenty and forty feet. Chamberlin estimates the average thickness of the drift in the Upper Mississippi Basin, in southwestern Ontario and the southern portion of the great northwestern plains of Canada to be 100 feet. Over the general area of the North German Plain Helland found that the glacial deposits averaged 150 feet in thickness. The presence of such deep accumulations of unconsolidated material has an important bearing on the soil moisture and water capacity of the soils of such regions, making both the water supply and its availability to crops much greater. It is true that agricultural regions outside the glacial districts have great thicknesses of residual soil cover, or are made up of great depths of essentially unconsolidated porous material. In regions with a cover of residual material, however, the soil tends to be removed from the slopes by erosion, and under preglacial conditions of topography the soils on the slopes of the Central Plains area of North America were probably comparatively thin. How great the contrast may be is suggested by descriptions of the topography of Indiana in the glaciated area and immediately to the south of it. Thus in the glaciated area: "The valleys begin on the uplands as scarcely perceptible grooves in the compact boulder clay, widen much more rapidly than they deepen, and seldom reach down to rock floor." South of the boundary of the Wisconsin drift

where the country has been little if at all modified by glaciation is found "a region of deep, narrow valleys, sharp irregular divides and precipitous cliffs." "The limit of drift encloses and fits this broken surface as a man's coat fits his shoulders."[24]

The fact that a large part of the Central Plains glaciated area of the United States is underlain by limestone gives additional importance to the present deep filling of glacial drift in connection with water supply and agriculture. As is typically now the case in Kentucky and parts of southern Indiana, these limestone regions probably had a sink hole topography and underground cavern drainage in preglacial times. Under such conditions surface drainage is often practically absent and water supplies from wells are not obtainable. Bowman[25] says: "The Prairie Plains do not have an exceptionally favorable rainfall. There is good reason for believing that were the surface less flat, the absorption of rain water less pronounced, the original forest would have been much more restricted." The thick drift deposits not only furnish unfailing supplies of water for crops and shallow wells throughout the areas of their distribution, but also, under special conditions, large volumes of artesian water, as on Long Island and at Ithaca, New York,[26] often used for irrigation purposes. These relations of the thick drift deposits to water supply conditions must, therefore, be also counted as one of the important favorable influences on agriculture due to glaciation.

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[24] Dryer, C. R.: Studies in Indiana Geography, Inland Pub. Co., Terre Haute, Ind., 1906, p. 19.

[25] Bowman, I.: Forest Physiography, New York, 1911, p. 460.

[26] Tarr, R. S.: Artesian Well Sections at Ithaca, N. Y., *Journ. of Geol.*, 1904, Vol. XII, No. 2, pp. 69-82.

(To be concluded)